

AD-A078 191

DAVID W TAYLOR NAVAL SHIP RESEARCH AND DEVELOPMENT CE--ETC F/G 13/10  
STATISTICAL MODELS OF SEWAGE WASTE GENERATION RATES ABOARD THE --ETC(U)  
DEC 79 W F HOFFMANN , J D DRETCHEN  
DTNSRDC/CMLD-78/10

UNCLASSIFIED

NL

1 OF 1  
AD-  
A078191

END  
DATE  
FILMED

1-80  
DDC



NATIONAL BUREAU OF STANDARDS  
MICROCOPY RESOLUTION TEST CHART

DTNSRDC/CMLD-78/10

STATISTICAL MODELS OF SEWAGE WASTE GENERATION RATES ABOARD THE  
USS HAROLD J. ELLISON (DD 864)

DDC FILE COPY

AD A 078191

LEVEL 1

22

**DAVID W. TAYLOR NAVAL SHIP  
RESEARCH AND DEVELOPMENT CENTER**

Bethesda, Md. 20084

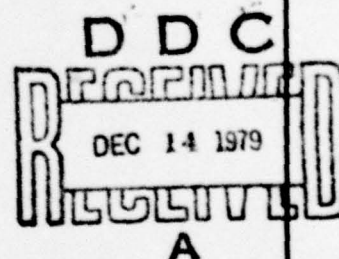


**STATISTICAL MODELS OF SEWAGE WASTE GENERATION RATES  
ABOARD THE USS HAROLD J. ELLISON (DD 864)**

by

Wolfgang F. Hoffmann  
Johann D. Dretchen

APPROVED FOR PUBLIC RELEASE: DISTRIBUTION UNLIMITED



**COMPUTATION, MATHEMATICS, AND LOGISTICS DEPARTMENT  
DEPARTMENTAL REPORT**

December 1979

DTNSRDC/CMLD-78/10

70 12 12 020

Accession For

NTIS G-2

DDC TAB

Unannounced

Justification

By

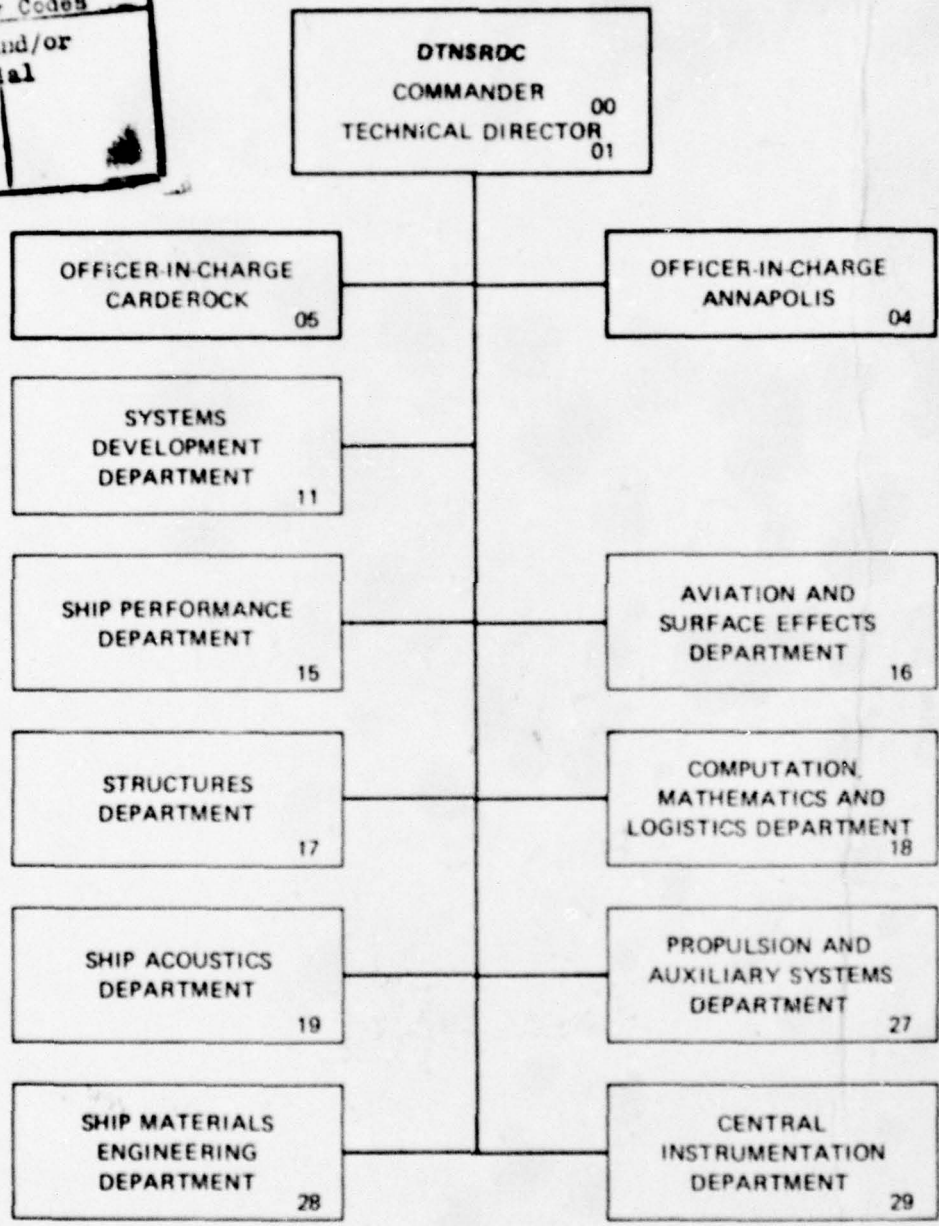
Distribution

Availability Codes

Dist Avail and/or special

A

# MAJOR DTNSRDC ORGANIZATIONAL COMPONENTS



UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER DTNSRDC/CMLD-78/18	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) STATISTICAL MODELS OF SEWAGE WASTE GENERATION RATES ABOARD THE USS HAROLD J. ELLISON (DD 864)		5. TYPE OF REPORT & PERIOD COVERED Interim Report Jul - Sep 78
7. AUTHOR(s) Wolfgang F. Hoffmann and Johann D. Dretchen		6. PERFORMING ORG. REPORT NUMBER
8. PERFORMING ORGANIZATION NAME AND ADDRESS David W. Taylor Naval Ship Research and Development Center Bethesda, Maryland 20084		9. CONTRACT OR GRANT NUMBER(s)
11. CONTROLLING OFFICE NAME AND ADDRESS Naval Sea Systems Command (SEA 0492P) Washington, D.C. 20362		10. PROGRAM ELEMENT PROJECT, TASK AREA & WORK UNIT NUMBERS FAC (QIN) Work Unit 2864-503
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office) 1232		12. REPORT DATE December 1979
		13. NUMBER OF PAGES 33
		15. SECURITY CLASS. (of this report) UNCLASSIFIED
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE
16. DISTRIBUTION STATEMENT (of this Report)  APPROVED FOR PUBLIC RELEASE: DISTRIBUTION UNLIMITED.		
17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)		
18. SUPPLEMENTARY NOTES		
19. KEY WORDS (Continue on reverse side if necessary and identify by block number) Navy Environmental Protection      Statistical Analysis Shipboard Waste Waters      Generation Rates Time Series Modeling		
20. ABSTRACT (Continue on reverse side if necessary and identify by block number) → Aft Head sewage waste generation data collected at 15-minute intervals onboard the USS HAROLD J. ELLISON, (DD864) both in port and at sea, are analyzed by Box-Jenkins time series analysis techniques. Results show that both in-port and at-sea data may be modeled by pure autoregressive Gaussian Processes with dependence order three for in-port data and order one for at-sea data. Maximum likelihood parameter estimates are provided and model fit checks are performed. A method is provided to extrapolate model results to other U.S. Navy ships.		

DD FORM 1 JAN 73 1473

EDITION OF 1 NOV 65 IS OBSOLETE  
S/N 0102-014-6601

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

406 847

JOB



## TABLE OF CONTENTS

	Page
LIST OF FIGURES.....	111
LIST OF TABLES.....	iv
ABSTRACT.....	1
ADMINISTRATIVE INFORMATION.....	1
INTRODUCTION.....	1
BASELINE FLOW DATA DESCRIPTION.....	2
MODEL DEVELOPMENT.....	5
GENERAL MODEL DESCRIPTION.....	5
IDENTIFICATION OF MODEL FORM.....	6
ESTIMATION OF PARAMETERS.....	6
MODEL IDIOSYNCRASY.....	11
DIAGNOSTIC CHECKS ON FIT.....	12
MODEL EXTRAPOLATION TO FLEET.....	21
REFERENCES.....	25
APPENDIX - BASELINE FLOW DATA LISTING.....	27

## LIST OF FIGURES

1 - Sample Flow Fluctuations--In Port.....	3
2 - Sample Flow Fluctuations--At Sea.....	4
3 - Autocorrelation and Spectral Density Estimates--In Port.....	9
4 - Autocorrelation and Spectral Density Estimates--At Sea.....	10
5 - Autocorrelation and Spectral Density Estimates of Residuals--In Port.....	13
6 - Autocorrelation and Spectral Density Estimates of Residuals--At Sea.....	14

	Page
7 - Autocorrelation and Spectral Density Estimates of In Port Simulation.....	19
8 - Autocorrelation and Spectral Density Estimates of At Sea Simulation.....	20

#### LIST OF TABLES

1 - Autocovariance, Autocorrelation and Spectral Density Estimates--In Port.....	7
2 - Autocovariance, Autocorrelation and Spectral Density Estimates--At Sea.....	8
3 - Maximum Likelihood Estimates of Model Parameters.....	11
4 - Autocovariance, Autocorrelation and Spectral Density Estimates of Residuals--In Port.....	15
5 - Autocovariance, Autocorrelation and Spectral Density Estimates of Residuals--At Sea.....	16
6 - Autocovariance, Autocorrelation and Spectral Density Estimates of In Port Simulation.....	17
7 - Autocovariance, Autocorrelation and Spectral Density Estimates of At Sea Simulation.....	18
8 - Per Capita MEAN and VAR Estimates for Model Application.....	23

## ABSTRACT

Aft Head sewage waste generation data collected at 15-minute intervals onboard the USS HAROLD J. ELLISON, (DD 864) both in port and at sea, are analyzed by Box-Jenkins time series analysis techniques. Results show that both in-port and at-sea data may be modeled by pure autoregressive Gaussian Processes with dependence order three for in-port data and order one for at-sea data. Maximum likelihood parameter estimates are provided and model fit checks are performed. A method is provided to extrapolate model results to other U.S. Navy ships.

## ADMINISTRATIVE INFORMATION

This task was accomplished under Work Unit 1-2864-503 as part of an overall project to characterize the waste streams of U.S. Navy ships as tasked to this Department under the Naval Environmental Protection Support Service (NEPSS) NCBC Project Order 8-0011.

## INTRODUCTION

The David W. Taylor Naval Ship Research and Development Center (DTNSRDC) surveyed sewage waste generation aboard the USS HAROLD J. ELLISON as part of an ongoing effort to characterize the non-oily aqueous waste streams discharged to the environment by U.S. Navy ships. Shipboard waste surveys, including this particular effort, are generally sponsored by the Navy Environmental Protection Support Service (NEPSS). In addition to the usual quantity and quality monitoring performed over the period 5 November 1974 to 23 March 1975, specific waste sources were monitored continuously over shorter periods to provide information on flow rate fluctuations at small time increments.

This report describes the methodology used in analyzing the flow rate fluctuation data obtained from continuous monitoring of the Aft Enlisted Head (combined commode and urinal flush wastes) and the resulting random process models deduced from the analysis. Although other major waste sources onboard the ELLISON were also monitored continuously, this report

is specifically limited to the Aft Enlisted Head source to demonstrate methodology and approach.

In the following report, it is assumed that the Aft Enlisted Head flow rate fluctuations can be characterized by a specific form of the family of Autoregressive Integrated Moving Average (ARIMA) models described by Box and Jenkins.<sup>1\*</sup> The basic philosophy and techniques of the Box-Jenkins stochastic model building approach (identification, estimation, checking) are used in this report, supplemented by more precise statistical techniques in the model identification portion of the analysis.

#### BASELINE FLOW DATA DESCRIPTION

The baseline flow data to which the analysis will be applied were obtained during the period 2-12 December 1974 from the Aft Enlisted Head soil drains. The recording method was an event recorder which provided an indicator mark on a strip chart each time a total of 10 gallons of waste passed through a metering device. Indicator marks were counted in each 15-minute period during the ten-day period. Small gaps (usually less than one hour) occurred at the time of strip chart replacement but, due to their infrequent occurrence and short duration, were assumed to represent zero flow periods. The resulting data provided a continuous flow record for a three-day at-sea period (3-5 December) and a six-day in-port period (6-11 December). Preliminary evaluation of the data indicated that 6, 7, and 8 December had significantly different flow characteristics from the rest of the period because of the inclusion of a debarkation day (6 December) and a weekend. These data were subsequently eliminated from consideration in the analysis, leaving three full days of waste flow data for normal in-port and at-sea operations.

The data presented in the Appendix are in units of tens of gallons per 15 minutes. Figures 1 and 2 show in-port and at-sea flow fluctuations, respectively, for one 24-hour period.

---

\*A complete listing of references is given on page 25.

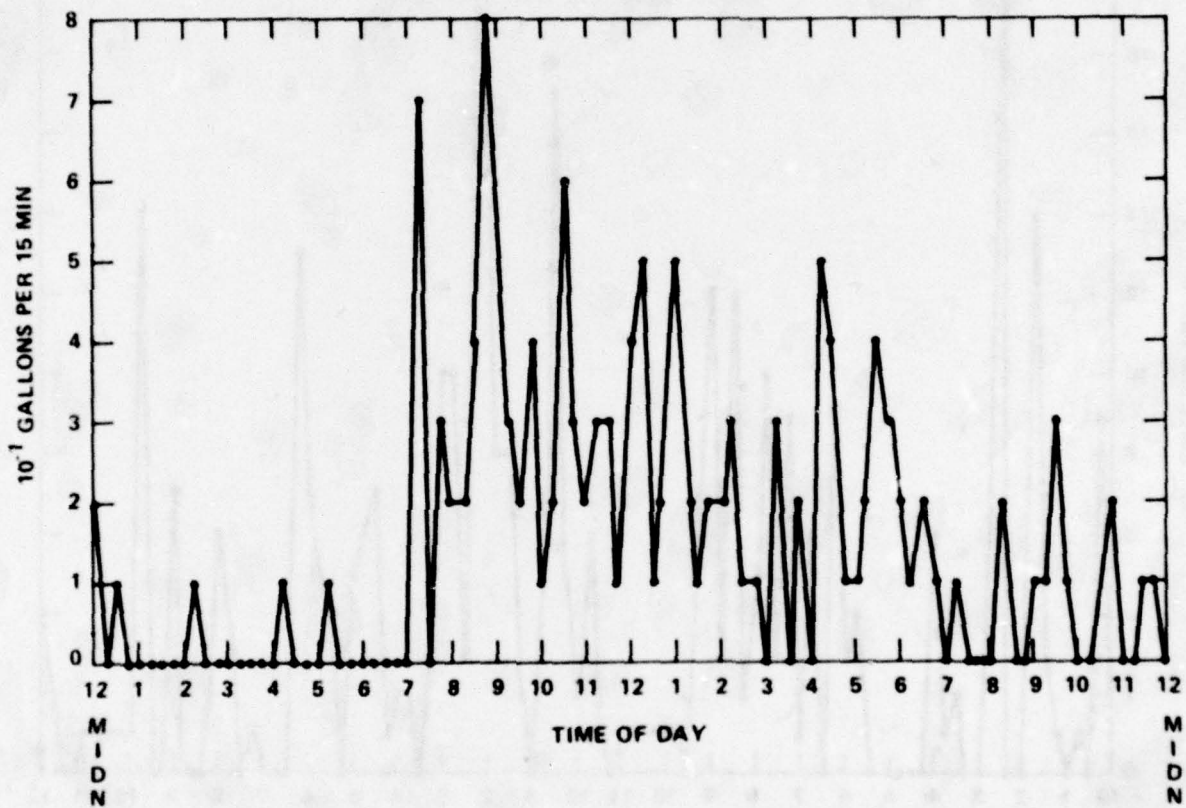


Figure 1 - Sample Flow Fluctuations  
IN PORT

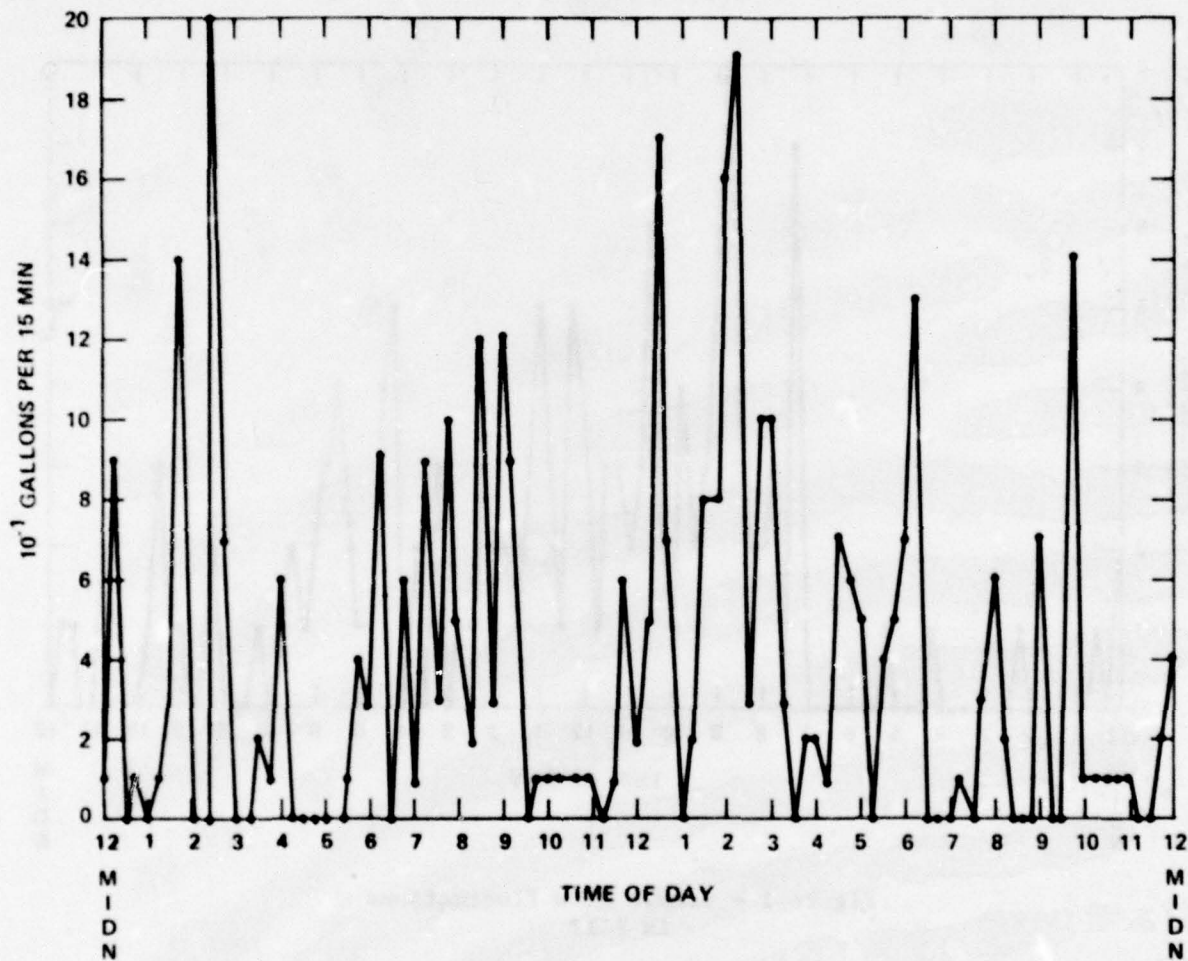


Figure 2 - Sample Flow Fluctuations  
AT SEA

## MODEL DEVELOPMENT

### GENERAL MODEL DESCRIPTION

The family of ARIMA random process models described by Box and Jenkins<sup>1</sup> provides a mathematical representation of a wide variety of characteristics of random fluctuations observed in time series. Stationary (constant mean), linear non-stationary (random mean level changes), and seasonal (cyclic-pattern repetition) are easily represented in this family of models.

Since the subsequent models identified are of the stationary form, we will briefly summarize the characteristics of this type of model. If  $z_t$ ,  $t=1,2,\dots$  represents the random values associated with a stationary time series, then the model form is

$$z_t = c + \phi_1 z_{t-1} + \phi_2 z_{t-2} + \dots + \phi_p z_{t-p} \\ + a_t - \theta_1 a_{t-1} - \theta_2 a_{t-2} - \dots - \theta_q a_{t-q}$$

where  $c$  is a constant

$\phi_i, \theta_j$  are constant coefficients

$a_t$  is a Normal (Gaussian) random variable with zero mean and variance  $\sigma_a^2$

$p, q$  are the dependence orders associated with  $z_t$  and  $a_t$ , respectively

As the model indicates, the current value of  $z_t$  is dependent on proportional values of  $p$  previous  $z$ 's and  $q$  previous  $a$ 's. The dependency relations are not intended to display causal relationships but merely reflect the fluctuation pattern as  $z$  evolves in time. No physical interpretation can therefore be assigned unless additional information is available.

The model is developed by first identifying the values  $p$  and  $q$  which define the order of dependence, estimating the parameter values  $\phi_i$ ,  $i=1,2,\dots,p$ ,  $\theta_j$ ,  $j=1,2,\dots,q$ , and then checking the fit by analysis of residual values. This sequence of procedures revolves around the autocorrelation estimates and defines the basic Box-Jenkins model building philosophy. The analysis procedures, the results of which are described

below, have been applied to the "at-sea" and "in-port" portions of the data of the Appendix separately.

#### IDENTIFICATION OF MODEL FORM

The autocovariance, autocorrelation, and spectral density estimates for the first twenty lags are given in Tables 1 and 2 for in-port and at-sea data, respectively. Figures 3 and 4 provide the corresponding information graphically. The structure of the flow variation shown in Figures 1 and 2 and the pattern of the autocorrelation and spectral density estimates indicate that both the in-port and at-sea fluctuations are stationary about a constant mean and are most likely pure autoregressive (AR) processes (i.e.,  $p > 0$ ,  $q=0$  in the general model described in the preceding section of this report).

To verify these initial indications and obtain optimal values for  $p$ , both sets of data were passed through IMSL<sup>2</sup> subroutine FTCOMP. FTCOMP did indeed verify the initial estimates and provided optimal values of  $p=1$  for the at-sea fluctuation and  $p=3$  for the in-port version, with  $q=0$  for both sets. In addition, FTCOMP confirmed the stationarity assumptions previously made. These results imply that the data are best fitted by pure autoregressive (AR) models of the form

in port

$$z_t = c + \phi_1 z_{t-1} + \phi_2 z_{t-2} + \phi_3 z_{t-3} + a_t$$

at sea

$$z_t = c + \phi_1 z_{t-1} + a_t$$

These models may be designated as AR(3) and AR(1), respectively.

#### ESTIMATION OF PARAMETERS

In addition to optimal selection of the model form, FTCOMP also provides Maximum Likelihood Estimates (MLE's) of the parameters of the selected model. Table 3 shows the results of these computations for both in-port and at-sea models and also shows the mean and variance estimates of each time series.

TABLE 1 - AUTOCOVARIANCE, AUTOCORRELATION AND SPECTRAL DENSITY ESTIMATES  
IN PORT

UNIVARIATE SPECTRAL ANALYSIS										
PARZEN WEIGHTING FUNCTION										
POST	LAG	SAMPLE UNWEIGHTED	SAMPLE AUTOCOVARIANCE WEIGHTED	UNWEIGHTED	WEIGHTED	SAMPLE AUTOCORRELATION WEIGHTED	SPECTRUM	SPECTRAL DENSITY	LOGARITHMIC SPECTRUM	PERIOD
	0	2.3407	2.3407	1.0000	1.0000	1.0000	1.77102	.7679	.24223	INFINITE
	1	.862716	.456345	.3664	.3592	.3592	1.40207	.5901	-.146769	40.0000
	2	.645024	.510197	.2706	.2559	.2559	.71050	.3396	-.131055	20.0000
	3	.652364	.581024	.2753	.2837	.2837	.337483	.1616	-.471749	13.3333
	4	.741646	.543283	.3111	.2514	.2514	.219519	.0921	-.658528	10.0000
	5	.746054	.536229	.3129	.2249	.2249	.244993	.1027	-.611044	8.0000
	6	.662714	.413644	.2708	.1334	.1334	.122372	.1351	-.492048	6.6667
	7	.575355	.300474	.2413	.1260	.1260	.154822	.1505	-.465121	5.7143
	8	.402644	.170721	.1649	.0716	.0716	.331453	.1630	-.476445	5.0000
	9	.267477	.451516-01	.1119	.0771	.0771	.238749	.1253	-.524694	4.4444
	10	.347027	.457246-01	.1274	.0840	.0840	.276634	.1163	-.554967	4.0000
	11	.304902	.561043E-01	.1266	.1236	.1236	.276645	.1182	-.561165	3.6364
	12	.233126	.338632E-01	.0779	.0125	.0125	.263516	.1195	-.579193	3.3333
	13	.327466	.241222E-01	.1376	.0118	.0118	.226431	.0960	-.565065	3.0769
	14	.174077	.951317E-02	.6719	.0340	.0340	.234446	.0479	-.678846	2.8571
	15	.600356-01	.187596E-02	.2252	.0308	.0308	.231772	.0433	-.650194	2.6667
	16	.159281	.254814E-02	.0668	.0011	.0011	.225654	.0467	-.646549	2.5000
	17	.205574	.135147E-02	.0441	.0066	.0066	.215174	.0302	-.667306	2.3529
	18	.995251E-01	.139050E-03	.0417	.0021	.0021	.212403	.0491	-.672845	2.2222
	19	.227815E-01	.569544E-05	.0094	.0000	.0000	.212443	.0491	-.672962	2.1053
	20	.602101E-01	.0254	.0254	.0000	.0000	.211127	.0496	-.675657	2.0000

OBSERVATIONS	244	MISSING	3	N OF LAGS	20	TIME UNIT MINUTE
VARIANCE RATIO	.174514E-01	DEGREES OF FREEDOM	51	STANDARDIZED BANDWIDTH	1.85430	VARIANCE
						2.34607

TABLE 2 - AUTOCOVARIANCE, AUTOCORRELATION AND SPECTRAL DENSITY ESTIMATES  
AT SEA

..... UNIVARIATE SPECTRAL ANALYSIS .....									
SEA	PARTEN WEIGHTING FUNCTION								
LAG	SAMPLE AUTOCOVARIANCE UNWEIGHTED	SAMPLE AUTOCOVARIANCE WEIGHTED	SAMPLE AUTOCORRELATION UNWEIGHTED	SAMPLE AUTOCORRELATION WEIGHTED	SPECTRUM	SPECTRAL DENSITY	LOGARITHMIC SPECTRUM	PERIOD	
0	23.7274	23.7274	1.0000	1.0000	7.92642	.3361	.490077	INFINITE	
1	5.07877	5.07877	.2616	.2616	7.43970	.3135	.871555	60.0000	
2	1.84370	1.74133	.0776	.0776	6.35655	.2679	.823222	28.0000	
3	2.32643	2.34080	.0981	.0981	5.33244	.2204	.726960	13.3333	
4	2.27124	1.81516	.0847	.0773	4.56345	.1973	.650293	10.0000	
5	3.12904	2.24900	.0132	.0095	4.03125	.1599	.605440	8.0000	
6	7.19144	.467310	.0103	.0109	3.91671	.1450	.592866	6.6667	
7	1.86831	.364236	.0774	.0804	3.81812	.1436	.590035	5.7143	
8	-1.07724	-.854630	-.0452	-.3192	3.58291	.1493	.569360	5.0000	
9	.582122	.193119	.0245	.0841	3.31249	.1496	.526154	4.4444	
10	-.844864	-.211712	-.0457	-.0849	3.58980	.1495	.549984	4.0000	
11	2.52647	.862644	.1265	.3194	3.99404	.1605	.591519	3.6364	
12	-.761646	-.374978-01	-.0321	-.3041	3.71075	.1504	.569462	3.3333	
13	-.207598	-.177546E-01	.0587	.0007	3.10524	.1309	.492896	3.0769	
14	.232944	.155814E-01	.2094	.0005	2.61444	.1102	.417452	2.9571	
15	-1.33161	-.811750E-01	-.0582	-.0014	2.12104	.0906	.326548	2.6667	
16	-.464647	-.741546E-02	-.0195	-.0003	1.91046	.0445	.281229	2.5000	
17	.962112	.689275E-02	.0405	.0003	2.42414	.1373	.385310	2.3529	
18	1.74447	.344944E-02	.0735	.0001	2.78299	.1173	.444512	2.2222	
19	-.711544E-01	-.177874E-04	-.0031	-.0000	2.20654	.0480	.363716	2.1053	
20	.100574	0	.0042	0	1.70711	.0710	.232263	2.0000	

OBSERVATIONS 244 MISSING 0 H OF LAGS 20 TIME UNIT MINUTE  
 VARIANCE RATIO .374514E-01 DEGREES OF FREEDOM 53 STANDARDIZED BANDWIDTH 1.85433 VARIANCE 23.7274

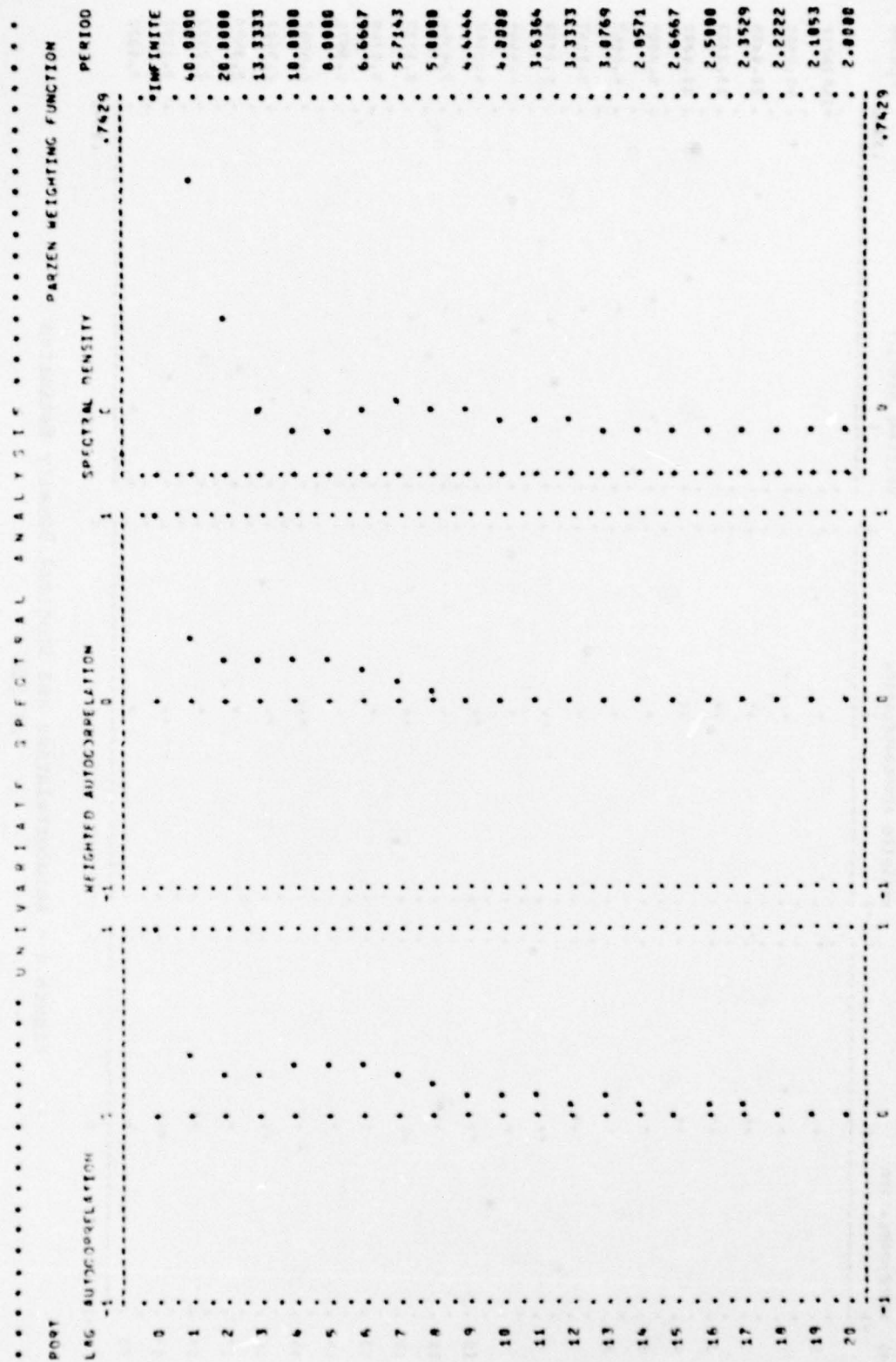


Figure 3 - Autocorrelation and Spectral Density Estimates  
 IN PORT

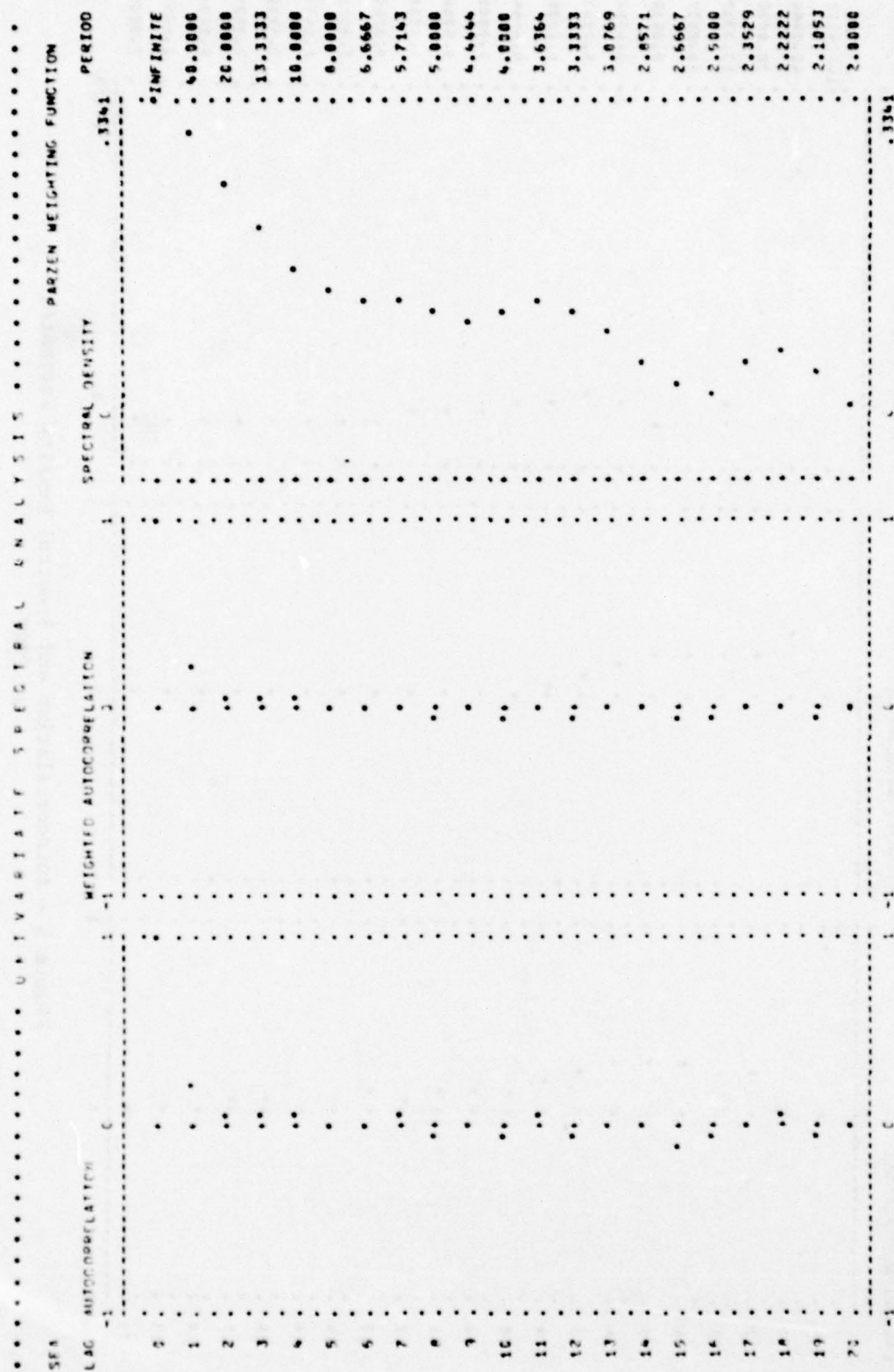


Figure 4 - Autocorrelation and Spectral Density Estimates  
AT SEA

TABLE 3 - MAXIMUM LIKELIHOOD ESTIMATES OF MODEL PARAMETERS

	Mean*	Var.**	C*	$\phi_1$	$\sigma_a^2$
At Sea	3.54	23.72	2.649	$\phi_1 = 0.252$	22.21
In Port	1.32	2.33	0.596	$\phi_1 = 0.278$ $\phi_2 = 0.109$ $\phi_3 = 0.161$	1.95
*In units of $10^{-1}$ gallons. **In units of $(10^{-1} \text{ gallons})^2$ .					

## MODEL IDIOSYNCRASY

ARIMA modeling requires the assumption of a Gaussian distribution for the white noise term  $a_t$  and, from theoretical considerations, the multivariate Gaussian distribution of the  $z$ 's. As a consequence, under certain conditions on the mean and variance of the distribution, large negative values have large probability of occurrence. This situation exists for both models (in port and at sea) and is incompatible with the physical reality of non-negative flow rates. To compensate for this idiosyncrasy in simulation applications, the following function should be used with the models:

$$w_t = \begin{cases} z_t & \text{if } z_t \geq 0 \\ 0 & \text{otherwise} \end{cases}$$

In probabilistic analyses, the usual Gaussian density integrals should be adjusted by multiplying the results by  $1/(1-\text{Prob}[Z_t < 0])$  where

$$\text{Prob}[Z_t < 0] \approx \begin{cases} 0.19 & \text{in port} \\ 0.23 & \text{at sea} \end{cases}$$

#### DIAGNOSTIC CHECKS ON FIT

Two types of diagnostic checks were performed to determine how well the model fits the data. The first type checks the autocorrelation of residuals for significant residual dependencies and the second checks the spectral density for suspicious periodicities.

Figures 5 and 6 are graphic displays of autocorrelation and spectral density estimates of the residuals shown in Tables 4 and 5. Under the assumption that the residuals are white Gaussian noise with variance  $\sigma_a^2$ , then the autocorrelation estimates,  $r_k$ , of the residuals at lag  $k$  should not exceed  $\pm 2\sigma(r_k) \approx \pm 2/\sqrt{n}$  ( $n$  is the number of sample points) for  $k > 0$ . Since  $n = 288$  for both in port and at sea,  $\pm 2\sigma(r_k) \approx \pm 0.118$ . It can be seen in Tables 4 and 5 that none of the autocorrelations of the residuals exceed these bounds, except, of course, at lag 0. A more formal check can be performed by computing the statistic

$$Q = n \sum_{k=1}^K r_k^2$$

which is Chi-Square distributed with  $(K-p)$  degrees of freedom (d.f.), where  $K$  is the number of lags for which the autocorrelation estimates have been computed. For the 20 lags shown in Tables 4 and 5

$$Q \text{ (in port)} = 0.031 \text{ with } (20-3) = 17 \text{ d.f.}$$

$$Q \text{ (at sea)} = 0.012 \text{ with } (20-1) = 19 \text{ d.f.}$$

both of which pass the 0.25 tabulated Chi-Square values by substantial margins. On the basis of these diagnostic tests, both models provide excellent fit to the data.

In the second type of check, the spectral estimates of the residuals, the spectral densities displayed in Figures 5 and 6 indicate some possibility of additional periodic components. However, these periodic components are thought to be the result of the truncation effects described in the previous section. To substantiate this assumption, simulation results for each truncated model, each simulation of length 288, were passed through the spectral analysis and are displayed in Tables 6 and 7 and Figures 7 and 8. These spectral estimates compare favorably in Tables 1 and 2 and Figures 3 and 4 of the original data. Consequently, it may be

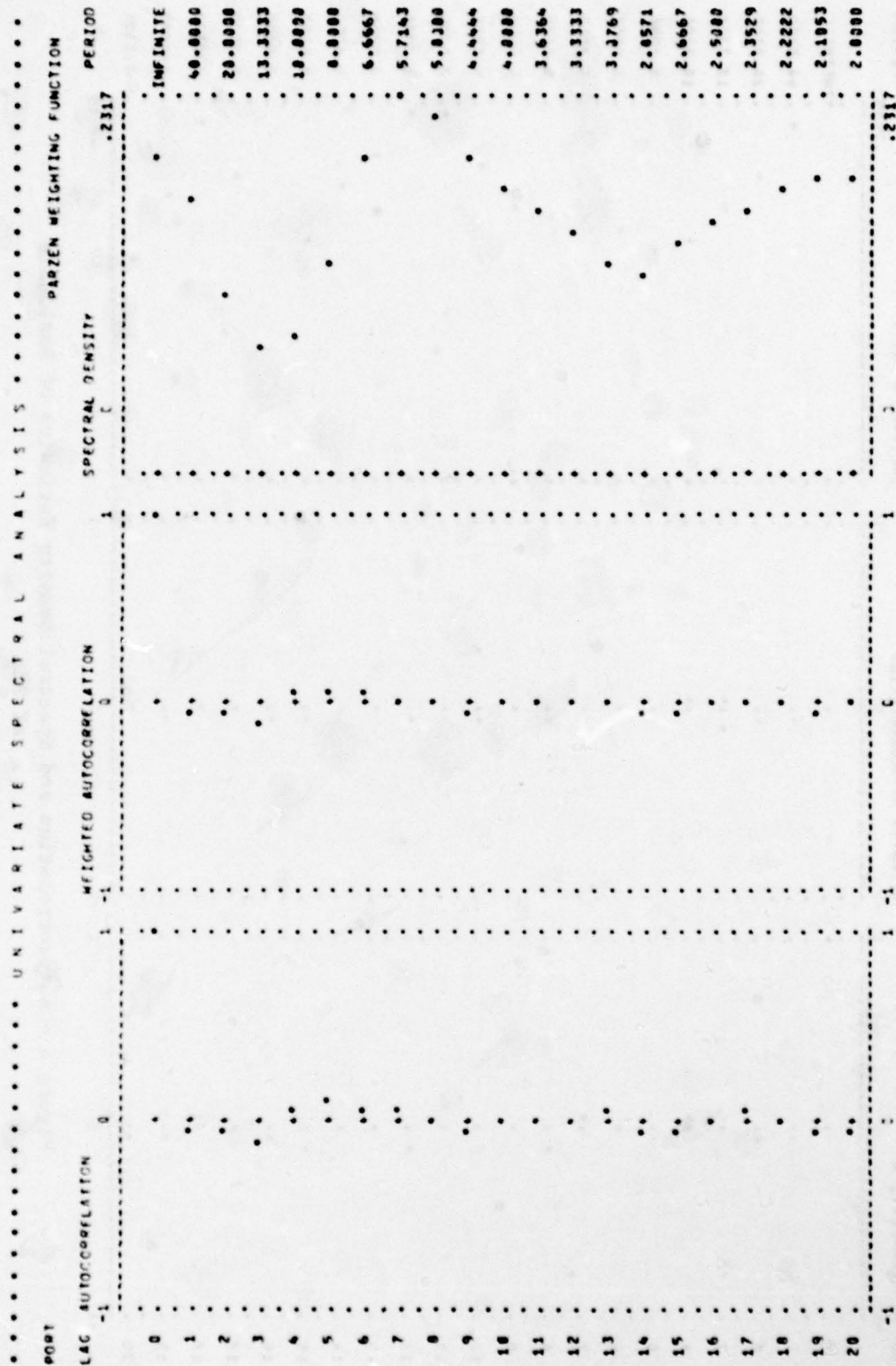


Figure 5 - Autocorrelation and Spectral Density Estimates of Residuals  
IN PORT

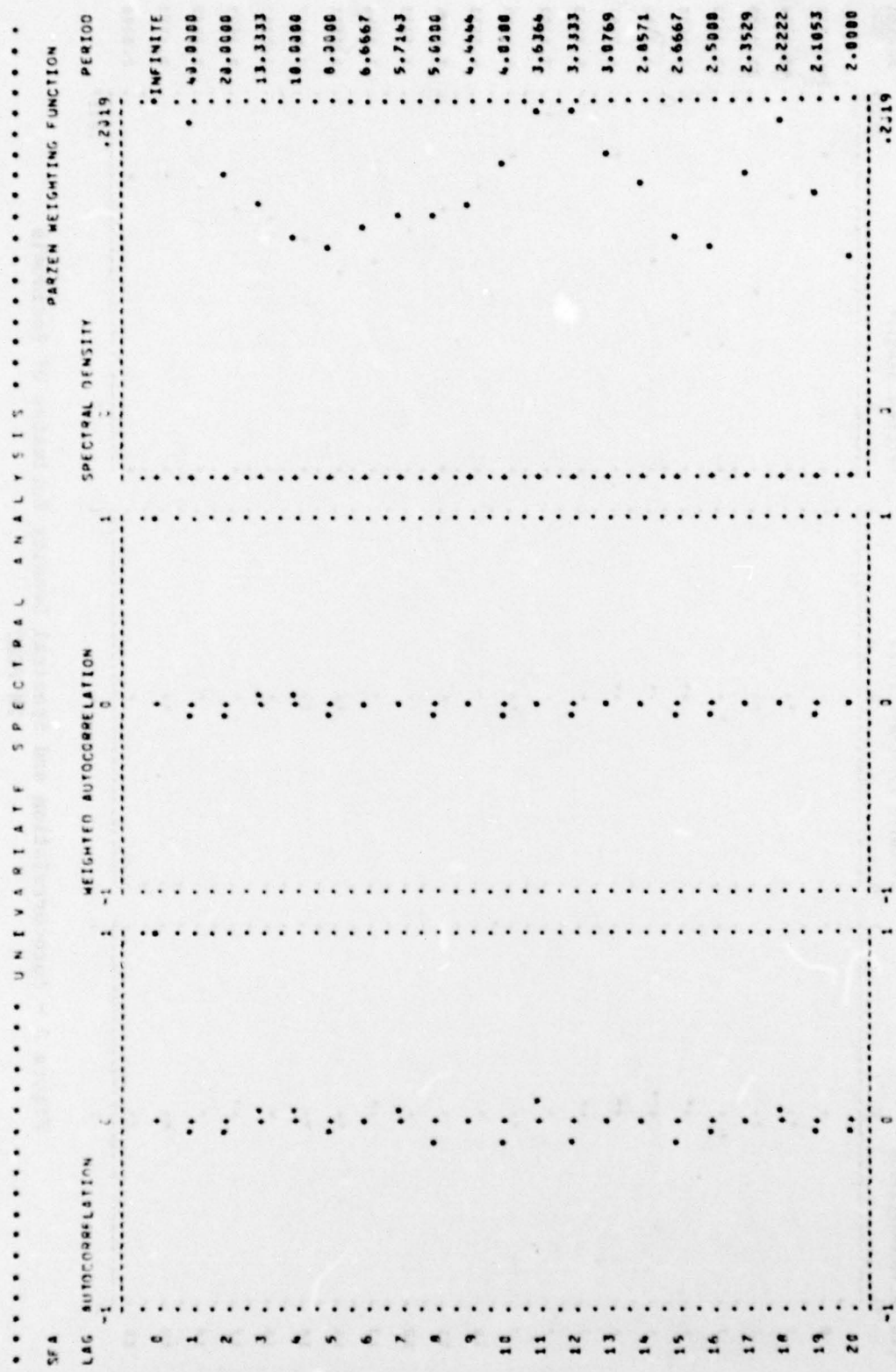


Figure 6 - Autocorrelation and Spectral Density Estimates of Residuals AT SEA

TABLE 4 - AUTOCOVARIANCE, AUTOCORRELATION AND SPECTRAL DENSITY ESTIMATES OF RESIDUALS  
IN PORT

UNIVARIATE SPECTRAL ANALYSIS									
LAG	SAMPLE AUTOCOVARIANCE UNWEIGHTED	SAMPLE AUTOCOVARIANCE WEIGHTED	SAMPLE AUTOCORRELATION UNWEIGHTED	SAMPLE AUTOCORRELATION WEIGHTED	SPECTRUM	SPECTRAL DENSITY	LOGARITHMIC SPECTRUM	PARZEN WEIGHTING FUNCTION	
								PERIOD	
0	1.95234	1.95234	1.0000	1.0000	.186698	.1991	-.10396	INFINITE	
1	-.50878E-01	-.572601E-01	-.0298	-.0293	.328377	.1642	-.683627	4.0000	
2	-.100967	-.954962E-01	-.0517	-.0489	.218392	.1119	-.660763	20.0000	
3	-.107425	-.165914	-.0960	-.0850	.156269	.0928	-.086127	13.3333	
4	.191024	.142271	.0927	.0749	.160082	.0861	-.774488	10.0000	
5	.255012	.193290	.1306	.0939	.226886	.1706	-.593654	8.0000	
6	.208531	.129706	.1068	.0664	.381187	.1952	-.418862	6.6667	
7	.151035	.788779E-01	.0774	.0464	.452442	.2817	-.344437	5.7143	
8	.188748E-01	.80459E-02	.0897	.0041	.436884	.2223	-.162426	5.0000	
9	-.764927E-01	-.251732E-01	-.0392	-.0130	.385933	.1977	-.613688	4.4444	
10	.62165E-01	.154613E-01	.0318	.0080	.166903	.1767	-.662302	4.0000	
11	.738346E-01	.134570E-01	.0378	.0069	.328949	.1644	-.493564	3.6364	
12	.108009E-01	.295835E-02	.0082	.0011	.295628	.1514	-.529266	3.3333	
13	.158957	.136305E-01	.0814	.0070	.251716	.1289	-.599898	3.0769	
14	-.351821E-02	-.189983E-03	-.0018	-.0001	.242164	.1240	-.615882	2.8571	
15	-.101239	-.316372E-02	-.0519	-.0016	.277657	.1422	-.556491	2.6667	
16	.487518E-01	.652229E-03	.0209	.0043	.384103	.1558	-.516979	2.5803	
17	.115431	.779157E-03	.0591	.0004	.319076	.1634	-.496106	2.3529	
18	.323506E-01	.667013E-04	.0171	.0000	.342267	.1753	-.465635	2.2222	
19	-.743212E-01	-.185803E-04	-.0381	-.0000	.359999	.1844	-.443698	2.1053	
20	-.113977E-01	0	-.0058	0	.164305	.1866	-.438535	2.0000	

OBSERVATIONS 248 MISSING 0 N OF LAGS 20 TIME UNIT MINUTE  
VARIANCE RATIO .374514E-01 DEGREES OF FREEDOM 53 STANDARDIZED BANDWIDTH 1.05433 VARIANCE 1.95238

TABLE 5 - AUTOCOVARANCE, AUTOCORRELATION AND SPECTRAL DENSITY ESTIMATES OF RESIDUALS  
AT SEA

..... UNIVARIATE SPECTRAL ANALYSIS .....									
SEA	SAMPLE AUTOCOVARANCE		SAMPLE AUTOCORRELATION		SPECTRUM		SPECTRAL DENSITY		PARZEN WEIGHTING FUNCTION
LAG	UNWEIGHTED	WEIGHTED	UNWEIGHTED	WEIGHTED	UNWEIGHTED	WEIGHTED	LOGARITHMIC SPECTRUM	PERIOD	
0	22.2212	22.2212	1.0000	1.0000	4.44695	4.44695	.2919	.651951	INFINITE
1	-.899707E-01	-.866892E-01	-.0040	-.0040	4.24644	4.24644	.1911	.628066	40.0000
2	-.120065	-.122967	-.0058	-.0055	3.72793	3.72793	.1678	.571668	28.0000
3	1.46274	1.27719	-.0649	-.0575	3.27984	3.27984	.1476	.515853	13.3333
4	1.75642	1.51789	-.0798	-.0638	2.98628	2.98628	.1343	.470848	10.0000
5	-.417672	-.333358	-.0188	-.0135	2.86882	2.86882	.1292	.454665	8.0000
6	.223874	.139249	-.0101	-.0063	3.02379	3.02379	.1361	.480551	6.6667
7	2.64362	1.26726	-.0920	-.0680	3.23163	3.23163	.1454	.509421	5.7143
8	-1.74923	-.761675	-.0787	-.0334	3.19822	3.19822	.1436	.503821	5.0000
9	1.10632	.167020	-.0498	-.0165	3.26314	3.26314	.1469	.513982	4.4444
10	-1.67940	-.619850	-.0756	-.0189	3.90666	3.90666	.1713	.580567	4.0000
11	3.64066	.563271	.1391	.0243	4.46873	4.46873	.2011	.658184	3.8364
12	-1.69650	-.131614	-.0674	-.0086	4.46897	4.46897	.2311	.650288	3.3333
13	.356528	.195722E-01	-.0163	-.0014	3.95811	3.95811	.1781	.597518	3.0769
14	.849281	.296602E-01	-.0247	-.0013	3.51657	3.51657	.1583	.546128	2.8571
15	-1.38757	-.431617E-01	-.0624	-.0020	2.96769	2.96769	.1335	.472486	2.6667
16	-.387682	-.623227E-02	-.0174	-.0003	2.83243	2.83243	.1268	.472225	2.5000
17	.699354	.472335E-02	-.0315	-.0002	3.68294	3.68294	.1657	.566194	2.3529
18	1.67281	.126566E-02	-.0735	-.0001	4.27629	4.27629	.1924	.631647	2.2222
19	-.54063	-.135112E-03	-.0243	-.0000	3.41621	3.41621	.1537	.533545	2.1853
20	-.261114	0	-.0114	0	2.65449	2.65449	.1195	.424845	2.0000

OBSERVATIONS 248 MISSING 0 N OF LAGS 20 TIME UNIT MINUTE

VARIANCE RATIO .374514E-01 DEGREES OF FREEDOM 53 STANDARDIZED BANDWIDTH 1.05430 VARIANCE 22.2212

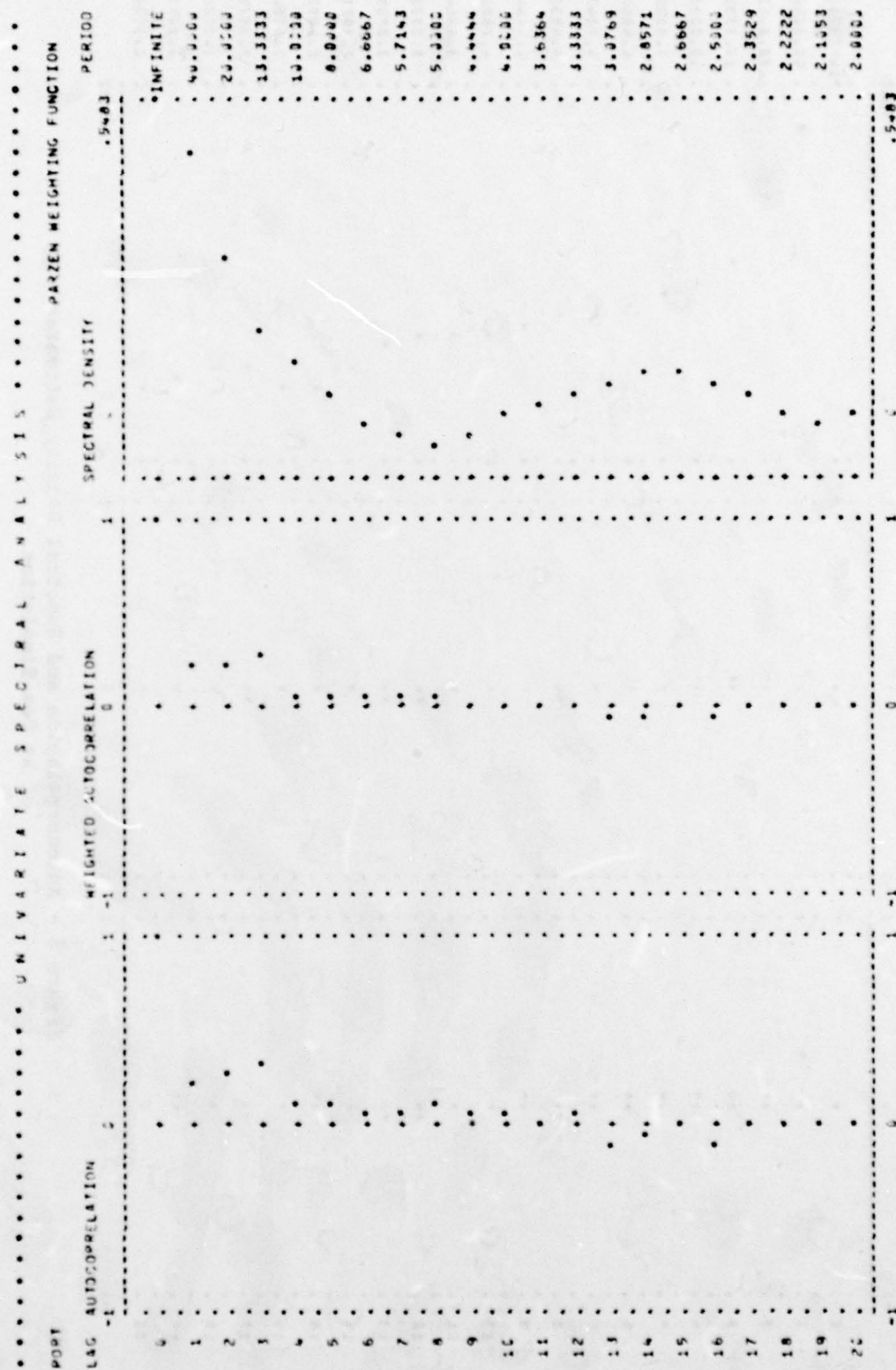
TABLE 6 - AUTOCOVARIANCE, AUTOCORRELATION AND SPECTRAL DENSITY ESTIMATES OF  
IN PORT SIMULATION

UNIVARIATE SPECTRAL ANALYSIS									
PARZEN WEIGHTING FUNCTION									
LAG	SAMPLE UNWEIGHTED	SAMPLE AUTOCOVARIANCE WEIGHTED	SAMPLE UNWEIGHTED	AUTOCORRELATION WEIGHTED	SPECTRUM	SPECTRAL DENSITY	LOGARITHMIC SPECTRUM	PERIOD	
0	1.8654	1.8654	1.8654	1.0000	1.12267	.5493	-.973746E-02	INFINITE	
1	.675224	.675224	.2568	.2512	.83355	.5763	-.535698E-01	40.0000	
2	.516149	.516149	.2075	.2725	.62451	.3230	-.226377	20.0000	
3	.627711	.555681	.3366	.2979	.482769	.2160	-.196364	13.3333	
4	.224841	.181072	.1266	.1974	.128491	.1718	-.696105	10.0000	
5	.213979	.153798	.1147	.1825	.747621	.1328	-.636213	8.0000	
6	.166837	.101916	.0895	.1557	.163568	.0877	-.786382	6.6667	
7	.199269	.104258	.1468	.1958	.115928	.0622	-.935811	5.7143	
8	.26354	.114555	.1397	.1592	.138509	.0582	-.964335	5.0000	
9	.110761	.393986E-01	.6637	.1211	.134587	.0722	-.970996	4.4444	
10	.179257	.448142E-01	.5961	.1240	.186382	.0999	-.729596	4.0000	
11	.427683E-01	.779663E-02	.5223	.1062	.295318	.1248	-.647264	3.6364	
12	.126811	.162318E-01	.5686	.1087	.242463	.1350	-.615398	3.3333	
13	.127360	.138216E-01	.5683	.1059	.267673	.1435	-.572403	3.0769	
14	-.672079E-01	-.254923E-02	-.1253	-.0014	.246317	.1535	-.543153	2.8571	
15	.582394E-01	.141998E-02	.6312	.1010	.249889	.1550	-.538368	2.6667	
16	-.125694	-.231111E-02	-.5674	-.1011	.281733	.1511	-.556167	2.5166	
17	.86621E-01	.544336E-03	.6432	.1003	.231630	.1242	-.635286	2.3529	
18	.115161E-01	.233295E-04	.6362	.1000	.174113	.0934	-.759176	2.2222	
19	.835669E-01	.208667E-04	.6448	.1000	.169742	.0918	-.774211	2.1953	
20	.218761E-01	0	.6117	0	.181938	.0975	-.746677	2.0000	

OBSERVATIONS	240	MISSING	0	N OF LAGS	22	TIME UNIT	MINUTE		
VARIANCE RATIO	.374514E-01				53	STANDARDIZED BANDWIDTH		1.85433	VARIANCE
									1.86564

TABLE 7 - AUTOCOVARIANCE, AUTOCORRELATION AND SPECTRAL DENSITY ESTIMATES OF  
AT SEA SIMULATION

UNIVARIATE SPECTRAL ANALYSIS										PARZEN WEIGHTING FUNCTION	
SEA											
LAG	SAMPLE AUTOCOVARIANCE UNWEIGHTED	SAMPLE AUTOCOVARIANCE WEIGHTED	SAMPLE AUTOCORRELATION UNWEIGHTED	SAMPLE AUTOCORRELATION WEIGHTED	SPECTRUM	SPECTRAL DENSITY	LOGARITHMIC SPECTRUM	PERIOD			
0	13.4534	13.4534	1.0000	1.0000	5.2282	.3982	.717938	INFINITE			
1	3.61732	3.76292	.2837	.7797	6.72743	.3516	.674625	48.0000			
2	1.67361	1.39186	.1095	.1636	3.71983	.2765	.570519	26.0000			
3	1.61586	1.25339	.1052	.1932	2.85516	.2145	.608170	13.3333			
4	1.61999	1.18735	.1055	.1853	2.51899	.1866	.399865	10.0000			
5	.780694	.561124	.0580	.1417	2.38392	.1507	.185770	8.0000			
6	.967526	.611851	.0719	.1447	2.28268	.1596	.358332	6.6667			
7	1.26029	.628853	.0892	.1466	2.16566	.1818	.335591	5.7143			
8	-.153369	-.651194E-01	-.0114	-.0048	2.12116	.1577	.326573	5.0000			
9	.956552	.316672	.0710	.0235	1.93078	.1495	.285732	4.4444			
10	.230339	.595948E-01	.0177	.0044	1.81507	.1369	.258994	4.0000			
11	.727281E-01	.132547E-01	.0054	.0010	1.87586	.1194	.231196	3.6364			
12	-.167254	-.218090E-01	-.0124	-.0016	1.87635	.1195	.273315	3.3333			
13	-.546002	-.664195E-01	-.0466	-.0035	1.73773	.1292	.239981	3.0769			
14	.686374	.327442E-01	.0451	.0024	1.60466	.1044	.147570	2.8571			
15	1.32094	.612008E-01	.0982	.0031	1.39581	.0815	.373444E-01	2.6667			
16	.251535	.432455E-02	.0187	.0003	1.46597	.0453	.595511E-01	2.5360			
17	-.105044	-.714448E-03	-.0079	-.0001	1.37123	.1319	.137110	2.3529			
18	.71333	.182666E-02	.0530	.0001	1.34943	.1033	.142838	2.2222			
19	.799731	.199333E-03	.0594	.0000	1.19120	.0875	.759846E-01	2.1053			
20	.271247		.0262	0	1.06726	.0743	.287202E-01	2.0000			
OBSERVATIONS	248	MISSING	0	N OF LAGS	20	TIME UNIT MINUTE					
VARIANCE RATIO	.374514E-01	DEGREES OF FREEDOM	51	STANDARDIZED BANDWIDTH	1.45433	VARIANCE	13.4534				



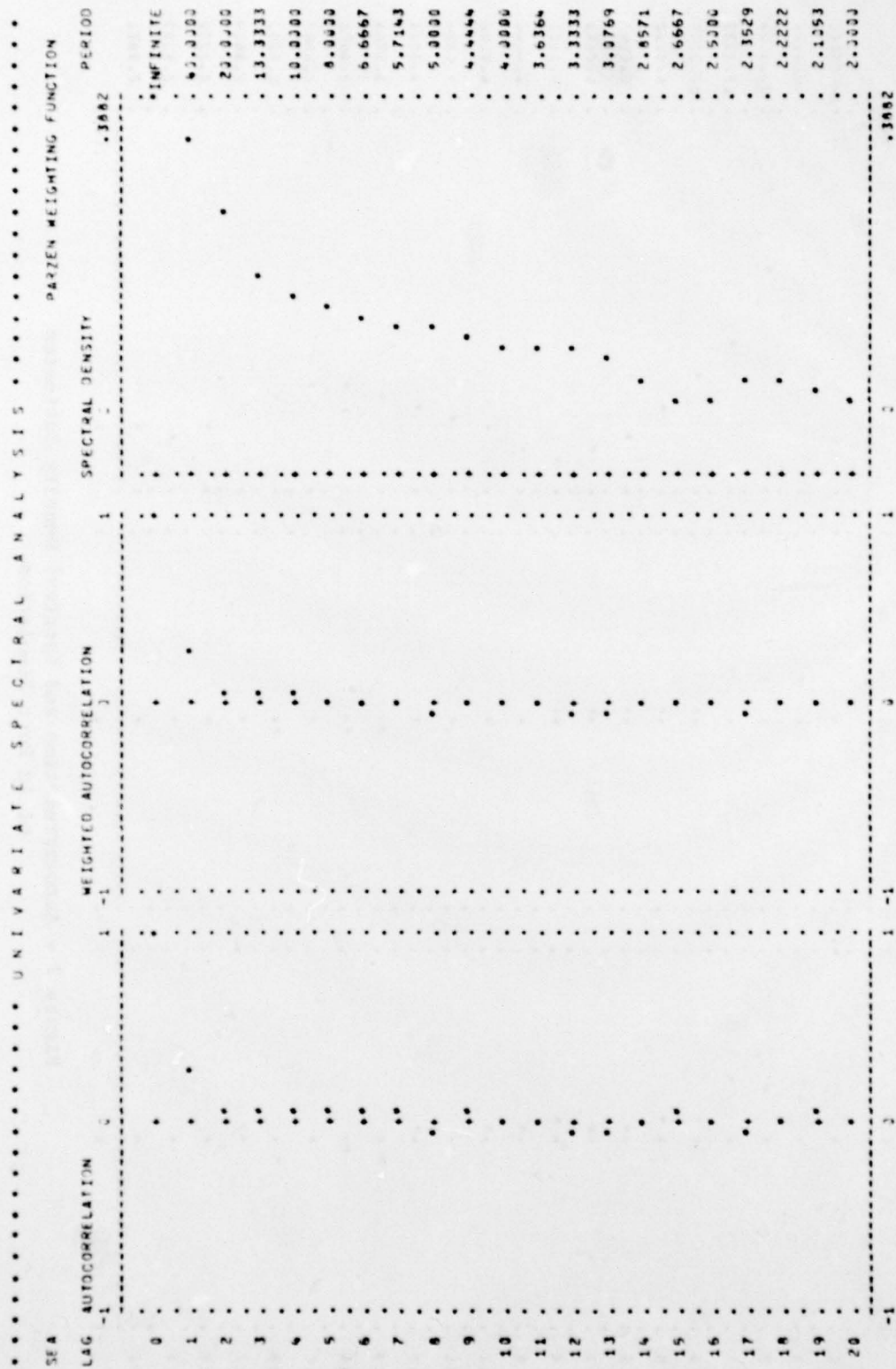


Figure 8 - Autocorrelation and Spectral Density Estimates  
of At Sea Simulation

concluded that the truncation function produces the apparent periodicities indicated in the spectral estimates of the residuals and no expansion of model forms is required.

#### MODEL EXTRAPOLATION TO FLEET

Although the flow fluctuation models developed in the previous sections are sufficient to characterize the Aft Head sewage flow rate onboard the USS HAROLD J. ELLISON, these models would be of little use unless some method is available which would allow application to other ships of the U.S. Navy Fleet. This section provides such a methodology and states the assumptions under which this extrapolation is valid.

The Aft Head source data on which the models are based consist of the volumes of combined commode and urinals flush water. Since flush water is directly related to complement, shipboard crew size information should be the principal extrapolation factor, assuming that crew habits and the quantity of water released per flush are consistent on a fleetwide basis. A standard practice is to repair/replace poorly maintained flushometers prior to the start of a NEPSS Shipboard Survey so that a consistent flush volume can be maintained and valid comparisons can be made among surveyed ships.

The second assumption, the fleetwide consistency of the crew's daily sanitary habits, is presumed to be reflected in the autocorrelation function pattern of the data. On a fleetwide basis in-port sewage generation is represented by an AR(3) process with the  $\phi_i$ ,  $i=1,2,3$  values as displayed in Table 3, and at-sea generation by AR(1) with  $\phi_1 = 0.252$ . Crew habits, however, are difficult to verify and consistency must be presumed for extrapolation purposes.

Under these assumptions, the only adjustments required to the parameter values of the models are for  $c$  and  $\sigma_a^2$ . These two parameters can be made dependent on ship's population level in the following manner:  $c$  and  $\sigma_a^2$  are related to MEAN and VAR of Table 3 by the formula

$$c = \text{MEAN} \times (1 - \phi_1 - \phi_2 - \dots - \phi_p)$$

$$\sigma_a^2 = \text{VAR} \times (1 - \phi_1 r_1 - \phi_2 r_2 - \dots - \phi_p r_p)$$

where the  $r_k$  are functions of the  $\phi_i$ 's only. MEAN and VAR values obtained from the Aft Head of the ELLISON may be reduced to 15-minute, per capita values by the method shown in Table 8. The results of Table 8 rest on the assumption that the ratio of Aft Head flow to Total Salt Water flow is equivalent to the ratio of Aft Head users to Total Ship population. This assumption is plausible since the total salt water flow consists of all commode and urinal flow on the ELLISON (including Forward Crew's Head and Officer's Head) as measured by survey over a 5-month period. It is also assumed that there is inconsequential head area crossover usage between Aft Crew, Forward Crew, and Officer Quarters. As a consequence, under the assumptions stated, designated model parameters can be adjusted to reflect changes in ships' force level.

To demonstrate the procedure, model parameters will be extrapolated to reflect the sewage generated by total crew of the ELLISON.

With an Average Total Ship's Crew of 135 in port and 205 at sea, we have

#### At Sea

$$\text{MEAN} = 205 \times 0.0268 = 5.494 \times 10^{-1} \text{ gallons/15 min.}$$

$$\text{VAR} = (205)^2 \times 13.6823 \times 10^{-4} = 57.500 \times (10^{-1} \text{ gallons/15 min.})^2$$

$$C = \text{MEAN} \times (1 - \phi_1) = 5.494(1 - 0.252) = 4.110 \times 10^{-1} \text{ gallons/15 min.}$$

$$\sigma_a^2 = \text{VAR} \times (1 - \phi_1^2) = 57.500 \times [1 - (.252)^2] = 53.849 \times (10^{-1} \text{ gallons/15 min.})^2$$

#### In Port

$$\text{MEAN} = 135 \times 0.01517 = 2.048 \times 10^{-1} \text{ gallons/15 min.}$$

$$\text{VAR} = (135)^2 \times 3.1708 \times 10^{-4} = 5.779 \times (10^{-1} \text{ gallons/15 min.})^2$$

$$C = \text{MEAN} \times (1 - \phi_1 - \phi_2 - \phi_3) = 2.048 \times (1 - 0.278 - 0.109 - 0.161) = 0.930 \times 10^{-1} \text{ gallons/15 min.}$$

$$\sigma_a^2 = \text{VAR} \times (1 - \phi_1 r_1 - \phi_2 r_2 - \phi_3 r_3) = 5.779 [1 - (0.278)(0.349) - (0.109)(0.206) - (0.161)(.256)] = 4.850 \times (10^{-1} \text{ gallons/15 min.})^2$$

$$\text{where } r_1 = (\phi_1 + \phi_2 \phi_3) / (1 - \phi_2 - \phi_1 \phi_3)$$

$$r_2 = \phi_1 r_1 + \phi_2$$

$$r_3 = \phi_1 r_2 + \phi_2 r_1 + \phi_3$$

TABLE 8 - PER CAPITA MEAN AND VAR ESTIMATES  
FOR MODEL APPLICATION

	In Port	At Sea
Aft Head Gallons/Day <sup>1</sup>	1664.9	3181.0
Total Saltwater Gallons/Day <sup>1</sup>	2587.8	4929.4
Ratio	0.643	0.645
Average Total Ship's Crew	135	205
Estimated Aft Head Users <sup>2</sup>	87	132
15 minute MEAN (TABLE 3)	1.32	3.54
15 minute VAR (TABLE 3)	2.40	23.84
15 minute MEAN/CAPITA <sup>3</sup>	0.01517	0.0268
15 minute VAR/CAPITA <sup>4</sup>	$3.1708 \times 10^{-4}$	$13.6823 \times 10^{-4}$

<sup>1</sup>Averages from 5 month survey.

<sup>2</sup>Ratio  $\times$  Average Total Ship's Crew.

<sup>3</sup>15 minute MEAN/Estimated Aft Head Users  
(in units of  $10^{-1}$  Gallons/Capita)

<sup>4</sup>15 minute VAR/(Estimated Head Users)<sup>2</sup>  
in units of  $(10^{-1}$  Gallons/capita)<sup>2</sup>

#### REFERENCES

1. Box, G.E.P. and G.M. Jenkins, "Time Series Analysis Forecasting and Control," revised edition, Holden-Day, Inc., San Francisco (1976).
2. "The IMSL Library Reference Manual," International Mathematical and Statistical Libraries, Inc., Houston, Texas (July 1977).

PRECEDING PAGE BLANK-NOT FILMED

APPENDIX  
Baseline Flow Data Listing

TIME OF DAY	AT SEA			IN PORT		
	DAY			DAY		
	(1)	(2)	(3)	(1)	(2)	(3)
0015	3	9	2	0	0	0
0030	2	0	10	0	1	0
0045	1	1	0	0	0	1
0100	1	0	0	0	0	0
0115	1	1	3	0	0	0
0130	0	3	2	0	0	0
0145	0	14	14	0	0	2
0200	0	0	5	0	0	0
0215	0	0	0	0	1	0
0230	0	20	2	0	0	0
0245	0	7	1	1	0	0
0300	0	0	0	1	0	0
0315	1	0	0	0	0	0
0330	0	2	0	0	0	0
0345	1	1	0	0	0	0
0400	11	6	4	0	0	1
0415	0	0	1	1	1	0
0430	0	0	5	0	0	0
0445	0	0	3	0	0	0
0500	0	0	0	1	0	0
0515	0	0	0	0	1	1
0530	9	1	0	0	0	0
0545	0	4	1	1	0	0
0600	0	3	0	2	0	0
0615	1	9	0	1	0	0
0630	2	0	0	0	0	0
0645	5	6	0	4	0	3
0700	3	1	1	1	0	4
0715	3	9	22	2	7	6
0730	1	3	6	2	0	2
0745	3	10	2	3	3	1
0800	6	5	2	3	2	4
0815	5	2	5	2	2	3
0830	1	12	7	2	4	3
0845	1	3	0	2	0	3
0900	2	12	2	1	5	3
0915	1	9	2	0	3	5
0930	3	0	0	0	2	1
0945	3	1	1	0	4	2
1000	7	1	14	0	1	3
1015	5	1	10	0	2	2
1030	2	1	0	1	6	2
1045	0	1	0	0	3	1
1100	5	1	1	1	2	2
1115	11	0	0	1	3	3
1130	2	1	5	0	3	1
1145	0	6	16	2	1	1
1200	5	2	1	3	4	1

TIME OF DAY	AT SEA			IN PORT		
	DAY			DAY		
	(1)	(2)	(3)	(1)	(2)	(3)
1215	11	5	1	1	5	2
1230	13	17	23	1	1	2
1245	23	7	15	1	2	4
1300	11	0	2	2	5	5
1315	6	2	0	2	2	0
1330	0	4	7	2	1	1
1345	0	8	11	3	2	1
1400	0	16	0	1	2	2
1415	0	19	11	5	3	3
1430	0	3	0	3	1	1
1445	7	10	17	1	1	1
1500	7	10	0	1	0	0
1515	0	3	2	2	3	1
1530	5	0	1	1	0	1
1545	0	2	0	1	2	11
1600	9	2	2	0	0	1
1615	5	1	0	1	5	2
1630	11	7	0	1	4	1
1645	0	6	5	3	1	2
1700	1	5	7	1	1	5
1715	1	0	1	0	2	1
1730	3	6	7	2	4	2
1745	1	5	4	2	3	2
1800	2	7	2	0	2	1
1815	6	13	2	1	1	4
1830	1	0	0	2	2	4
1845	2	0	1	2	1	1
1900	2	0	1	3	0	0
1915	24	1	0	1	1	1
1930	12	0	1	1	0	2
1945	7	3	1	2	0	2
2000	6	6	1	1	0	1
2015	9	2	0	0	2	1
2030	2	0	0	0	0	1
2045	1	0	0	1	0	0
2100	15	7	0	0	1	0
2115	11	0	1	1	1	2
2130	9	0	2	2	3	2
2145	0	14	0	1	1	2
2200	0	1	0	1	0	2
2215	0	1	0	0	0	0
2230	0	1	4	1	1	0
2245	0	1	1	0	2	1
2300	0	1	0	0	0	0
2315	0	0	0	1	0	1
2330	2	0	0	1	1	0
2345	0	2	0	0	1	1
2400	1	4	0	2	0	1

# INITIAL DISTRIBUTION

## Copies

4	NAVSEA
	1 SEA 03F
	1 SEA 0331F
	1 SEA 04E
	1 SEA 534
1	NAVFAC
	1 FAC 112
3	CBC Port Hueneme
	1 CBC 251
	1 CBC 251C
	1 CEL L54
12	DTIC

## CENTER DISTRIBUTION

Copies	Code	Name
1	1800	G.H. Gleissner
2	1809.3	D. Harris
1	1840	H.J. Lugt
1	286	H.H. Singerman
9	2863	G.B. Nickol
1	522.1	Unclass Lib (C)
1	522.2	Unclass Lib (A)

PRECEDING PAGE BLANK-NOT FILMED

**DTNSRDC ISSUES THREE TYPES OF REPORTS**

1. DTNSRDC REPORTS, A FORMAL SERIES, CONTAIN INFORMATION OF PERMANENT TECHNICAL VALUE. THEY CARRY A CONSECUTIVE NUMERICAL IDENTIFICATION REGARDLESS OF THEIR CLASSIFICATION OR THE ORIGINATING DEPARTMENT.

2. DEPARTMENTAL REPORTS, A SEMIFORMAL SERIES, CONTAIN INFORMATION OF A PRELIMINARY, TEMPORARY, OR PROPRIETARY NATURE OR OF LIMITED INTEREST OR SIGNIFICANCE. THEY CARRY A DEPARTMENTAL ALPHANUMERICAL IDENTIFICATION.

3. TECHNICAL MEMORANDA, AN INFORMAL SERIES, CONTAIN TECHNICAL DOCUMENTATION OF LIMITED USE AND INTEREST. THEY ARE PRIMARILY WORKING PAPERS INTENDED FOR INTERNAL USE. THEY CARRY AN IDENTIFYING NUMBER WHICH INDICATES THEIR TYPE AND THE NUMERICAL CODE OF THE ORIGINATING DEPARTMENT. ANY DISTRIBUTION OUTSIDE DTNSHDC MUST BE APPROVED BY THE HEAD OF THE ORIGINATING DEPARTMENT ON A CASE-BY-CASE BASIS.